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Paper 21

Using Artificial Intelligence Techniques to Predict the Behaviour of Masonry Panels

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Abstract

Laboratory experimental data is often erroneous. This error is more apparent in data obtained from testing of anisotropic composite materials such as masonry wall panels. In this paper data colleted from the laboratory tests of masonry panels is presented. Methodologies for reducing (correcting) error in laboratory tested data are discussed. The concept of stiffness/strength corrector to model the variation in masonry properties in laterally loaded masonry panels was introduced by Zhou [1] and Rafiq et al [2] to model variation in masonry properties. A cellular automata (CA) technique was used to model the boundary effect and establish stiffness/strength corrector values for unseen panels, using zone similarity techniques introduced by Zhou et al [3] These stiffness/strength correctors are then used in a non-linear finite element analysis (FEA) to predict the failure load and failure pattern of these unseen panels. This paper demonstrates that methodologies for reducing error in experimental data can further improve the predicted failure load of the panels.

Keywords: corrector factor, cellular automata.

1 Introduction

Masonry is a material composed of two completely different constituents, which when combined together produce a highly variable composite material. However due to this highly composite nature of the constituents of this material it has been very difficult to accurately predict the behaviour of masonry elements. Research carried out by Lawrence [4] indicated that it is essential to consider an inherent random variation in masonry properties, in any theoretical analysis to produce a better prediction of the behaviour of laterally loaded masonry panels.

Research in the University of Plymouth by Zhou [1] and Rafiq et al [2], has proposed a novel approach for the analysis of masonry panels subjected to lateral loading, which gives a much closer prediction of both failure load and failure patterns. This method is based on the proper modelling of the variation in masonry properties in various locations within the panel and more importantly, properly modelling the effect of panel boundaries, which has been proved by this research to have a dominant effect on the behaviour of panels subjected to lateral loading. The research has introduced a new concept, "stiffness/strength corrector" Zhou [1], which quantifies the boundary effects and properly models the variation in masonry properties at various locations (zones) within a masonry wall panel. Derivation of these correctors was based on a closer mapping of laboratory experimental results, carried out by Chong [4], with those obtained from a non-linear finite element analysis of full-scale masonry wall panels subjected to a uniformly distributed lateral load. The finite element program was originally developed by Ma and May [5] and further developments were introduced by Chong [4] and Zhou [1] and Zhou et al [3], used a cellular automata (CA) to model the effect of various boundary (edge support) types. This research used a single leaf brick panel for which stiffness/strength correctors were determined as the 'base panel', i.e. the panel from which all other panel correctors could be predicted. This research also introduced the concept of zone similarities, using CA, which enable, corrector values at various zones inside the base panel to be mapped on to any unseen panel with various boundary types and for panels with or without opening, to determine corrector values. The corrector values were then used in a non-liner FEA program to estimate the failure load and failure pattern for unseen masonry panels.

Research by Zhou [1] demonstrated that it was possible to achieve an improvement of about 20% in the failure load capacity of the laterally loaded masonry wall panels. Although considerable improvements were achieved in the failure load and failure pattern of the masonry panels, errors in the experimental results made comparison of the analytical and experimental load deflection results inconclusive.

The research presented in this paper extends the previous research by introducing methodologies for minimising the error in the laboratory test data and concentrates on reducing the error between analytical and measured load deflection data at various locations on a panel. Case studies will be presented to demonstrate that it is possible to improve load deflection and failure load capacity of the panels. The research also introduces a methodology for handling scaling effects when establishing corrector values for unseen panels which are different in their size to those of the base panel.

2 A brief overview of the previous research

Figure 1 shows location of the measurement points on the base panel. This panel was a solid single leaf clay brick masonry wall panel. Linear Variable Differential Transformers (LVDTs) were placed at each gridline intersection. The panel was loaded using an air bag, which was a common procedure for applying uniform lateral load on the face of the panel. The panel was simply supported along its vertical edges, fixed at its base and free at the top. The load was gradually increased on the panel and deflection data was recorded at intervals of 0.2 kN/m^2. It was observed that at the initial stage of the test the right hand edge of the panel was moved until the sides of the panel were fully in contact with the supporting edges. Figures 2 shows a 3 dimensional surface plot of the experimental load deflection data at every measurement location and Figure 3 shows a line plot of the load deflection data along gridline C (across the width of the panel) at various load levels.

Evidence of movement in the right hand support is clear in Figures 2 and 3. Irregularities in the surface plot in Figure 2 and in line plot in Figure 3 clearly show inaccuracies in the laboratory recording data. This error in more pronounced at lower load values (up to 1.6 kN/m^2). From the surface plot of deflection in Figure 2 it is also clear that their was no data available at locations near the bottom support of the panel. This has resulted an a flat surface near that area which is not a true representation of the deflected shape for this type of panel.

Figure 4 shows individual load deflection plots at various recording points along gridline C. The evidence of irregularities at locations near the boundaries of the panel (Points C1 and C9) is more pronounced. Figure 4 better demonstrate the existence of error in recording data as at certain load levels the deflection is moving in the wrong direction as the load is increased. Moreover, it was expected that the deflected shape of the panel should be symmetrical about its vertical centreline (about gridline 5). From Figures 2 and 3 it is clear that this was not the case with the measured data. Methodologies for minimising the error in the laboratory data to reflect the real response of panels under applied lateral load are discussed in the following section.

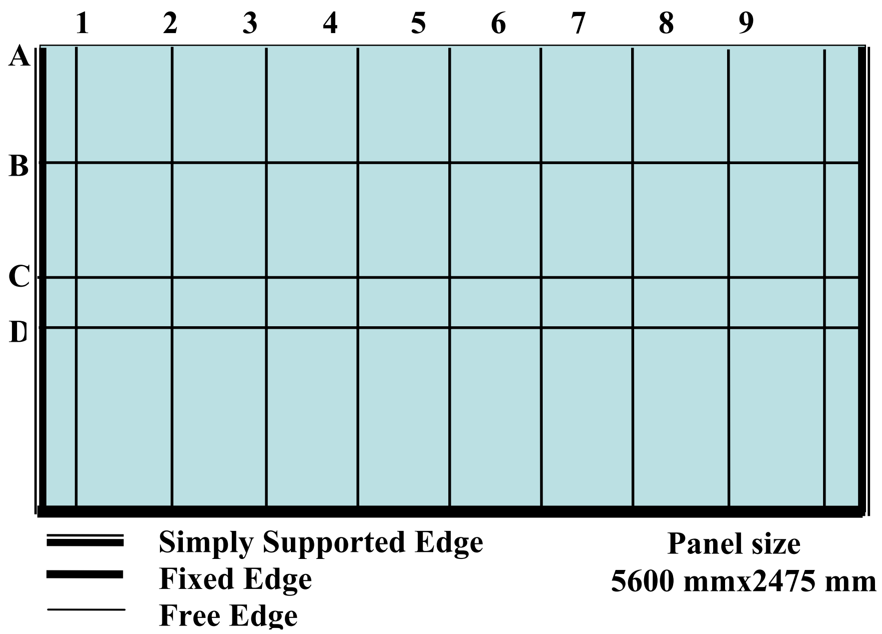

Figure 1 position of recorded measurement points on the ‘base panel’

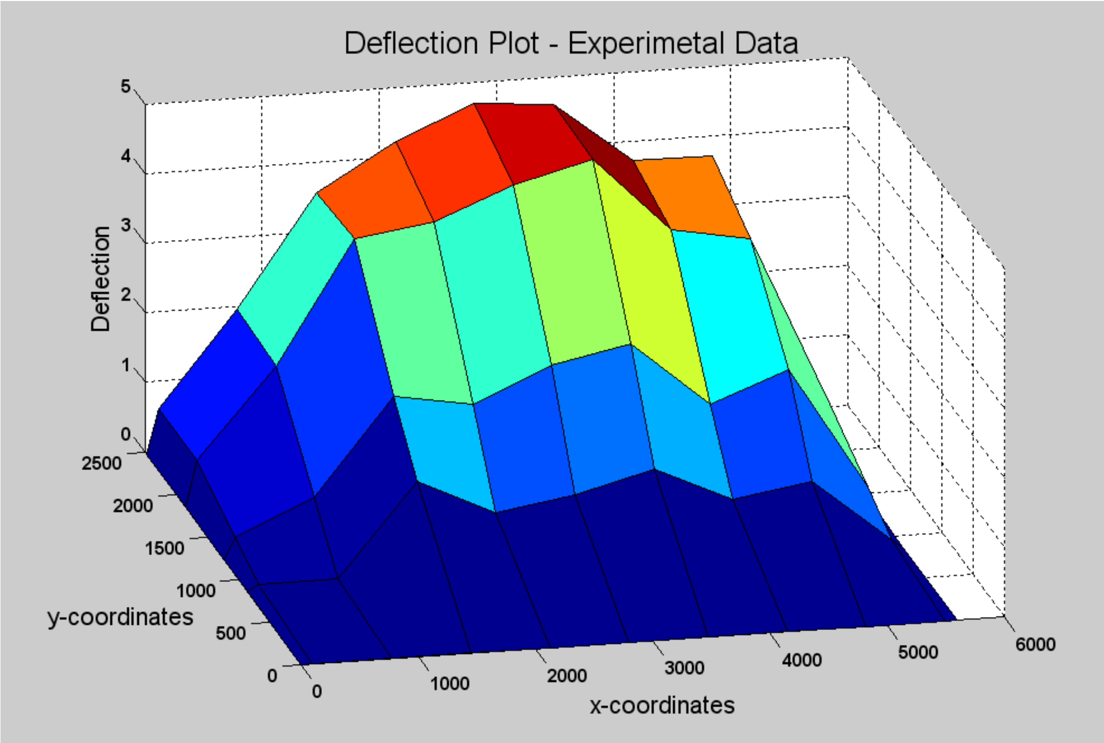

Figure 2. surface plot of experimental deflection data (at 1.8 kN/m^2)

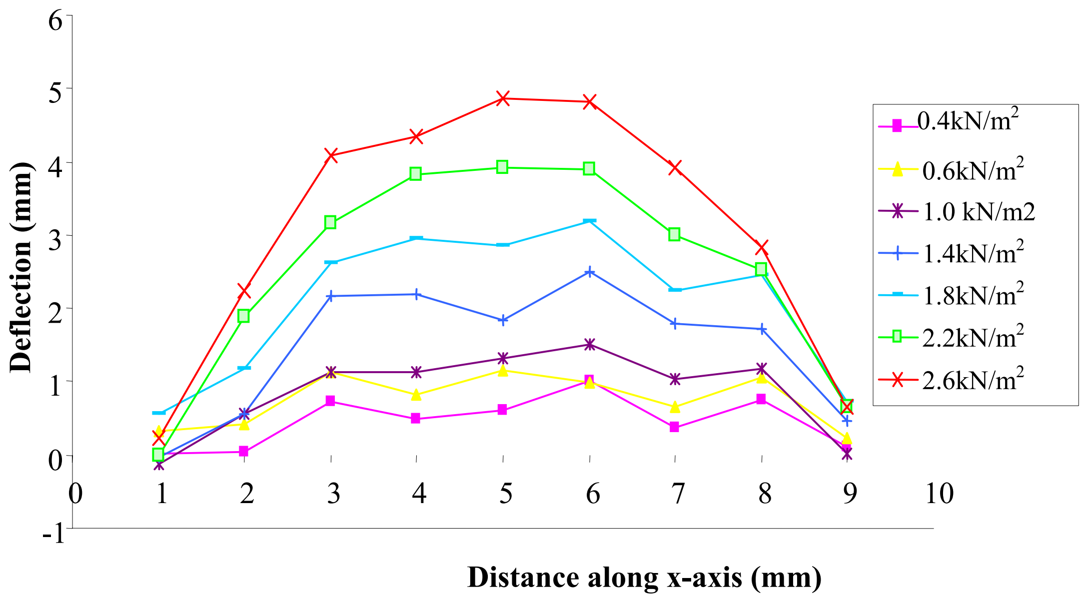

Figure 3 Measured deflection along grid line C at various load levels

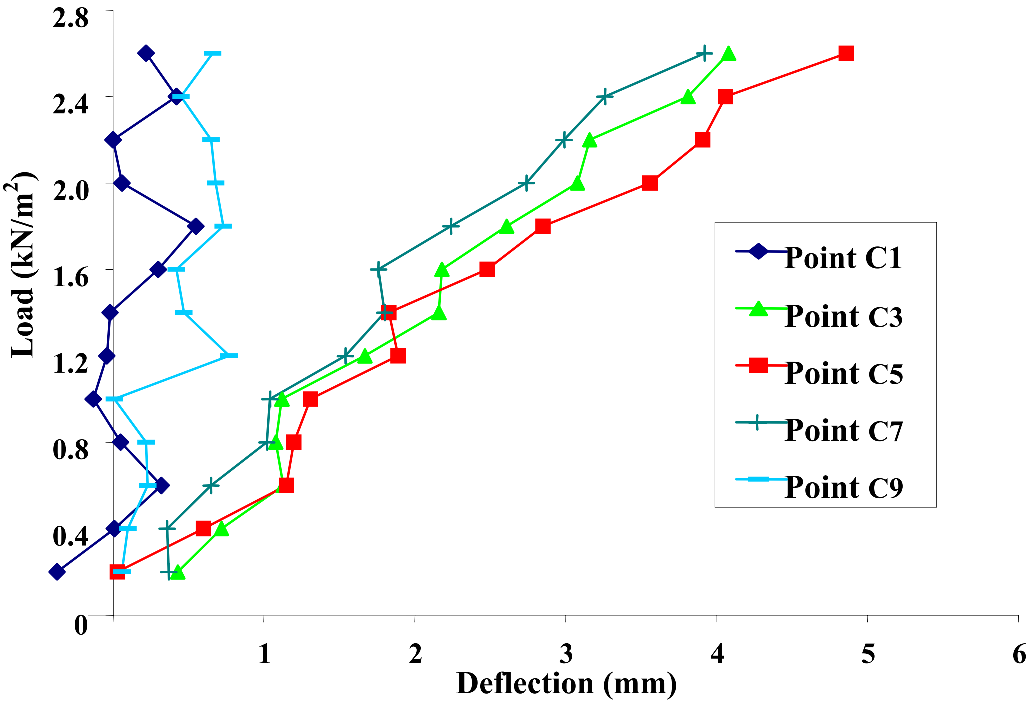

Figure 4 Load Deflection plot at various points along grid C

3 Methodologies for reducing errors in laboratory data

An in depth investigation was carried out to reduce the error in the laboratory data to reflect the real response of the panel under the uniformly distributed lateral load in order to be able to compare a like with like situation both for the FAE and experimental results. The first step was to carry out a regression analysis both on the 3D data and 2D linear data to find a better fit between the expected experimental data and the FEA model in order to minimise discrepancies in actual experimental data as depicted in Figure 4.

3.1 Three dimensional surface

In this analysis the following three different regression models were investigated to fit the experimental data:

Polynomial function;
Trigonometric function; and
Timoshenko [6] like function.

The result of the three analyses is presented in Figure 5. From Figure 5 it is clear that all three curves give a good fit to the experimental data while maintaining symmetry about the centreline of the panel. A more detailed investigation proved that the Timoshenko type surface was a better fit with the experimental data and with the real situation.

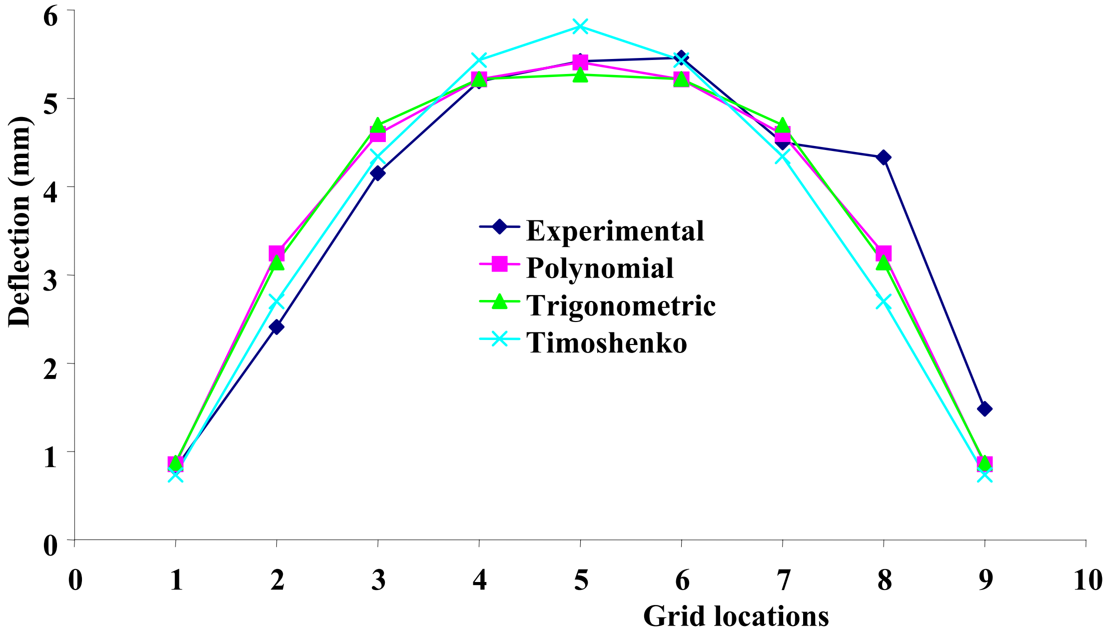

Figure 5 Load deflection plots along grid A using various regression rules

Figure 6 shows a comparison of load deflection plot of the experimental data with that of the chosen Timoshenko type regression results. Once again, from Figure 6 it is clear that the chosen curve not only gives a better fit with the experimental data at various load levels, but also eliminates the unexpected irregularities in the load deflection plots near the boundaries of the panel.

The final relationship used to simulate the expected deformed shape of the base panel under a uniformly distributed load is given below:

$$F1 = A_1 * \cosh(\pi * Y/L_x) + A_2 * \pi * Y/L_x * \sinh(\pi * Y/L_x) + A_3 * \sinh(\pi * Y/L_x) - A_3 * Y * \pi/L_x * \cosh(\pi * Y/L_x)$$

and

$$F2 = \pi^4/96 * \sin(\pi * X/L_x)$$

And finally the final deformed shape is represented by:

$$Z = A_0 * F_2 + F_1 * \sin(pi * X/L_x) + C$$

Where:

A_0, A_1, A_2 and A_3 are constants

L_x and L_y represent the width and height of the panel respectively and

X and Y represent X and Y coordinates of any point on the panel

Z is the vertical deflection at location (X,Y)

The constant C was introduced here to model possible movement at the edges of the panel.

The Timoshenko type regression formula allows a better satisfaction of the panel boundary conditions, such as $\frac{\partial Z}{\partial x}\big|_{(x=o \text{ and } x=Lx)}=0$ and $\frac{\partial Z}{\partial y}\big|_{y=0}=0$.

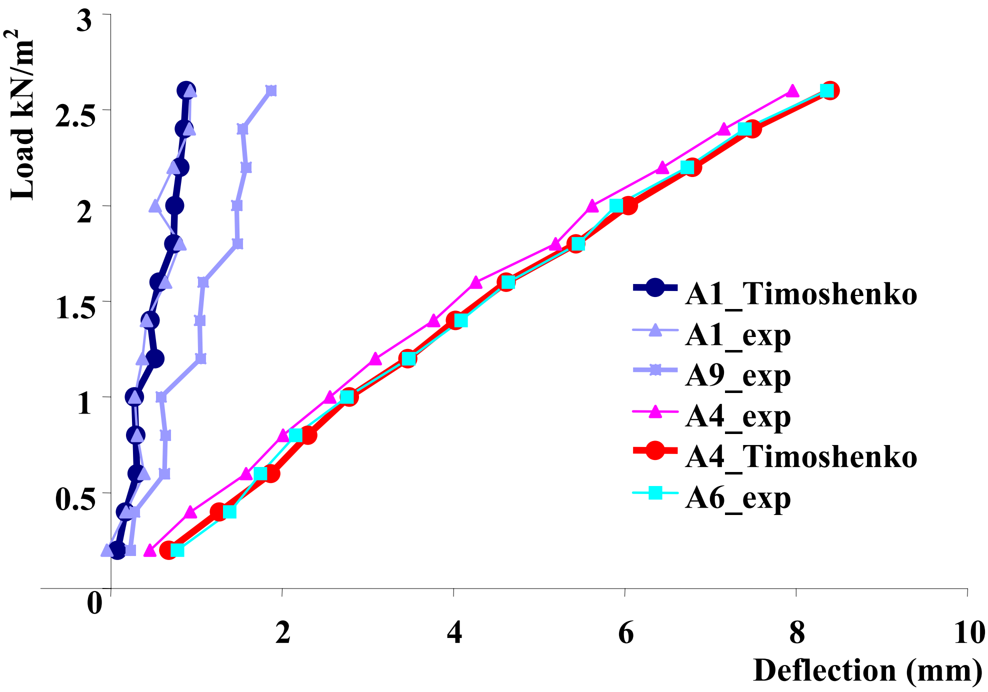

Figure 6 Load deflection plots – a comparison of experimental and corrected deflection along Grid A

3.2 Modified corrector values

As discussed earlier, the stiffness/strength corrector concept introduced by Zhou [1] was based on a closer mapping of laboratory experimental results, with those obtained from a non-linear finite element analysis of full-scale masonry wall panels subjected to a uniformly distributed lateral loads. In order to maintain symmetry and eliminate irregularities in experimental load deflection data near the panel boundaries, as discussed in the previous section, in this research stiffness/strength corrector values are based on the comparison of the FEA results with those obtained from a Timoshenko type regression results. The following section describes how the corrector values are improved using several iterations.

3.3 Iteration method

The corrector values derived by Zhou [1] were calculated as:

$$\Psi = \frac{W_{FEA}}{W_{Exp}}, \quad \text{and} \quad D_{\Psi} = D * \Psi$$

Where:

W = deflection at any point on the panel

D = Flexural Rigidity and

Ψ = corrector values

A surface plot of Zhou's corrector values is given in Figure 7.

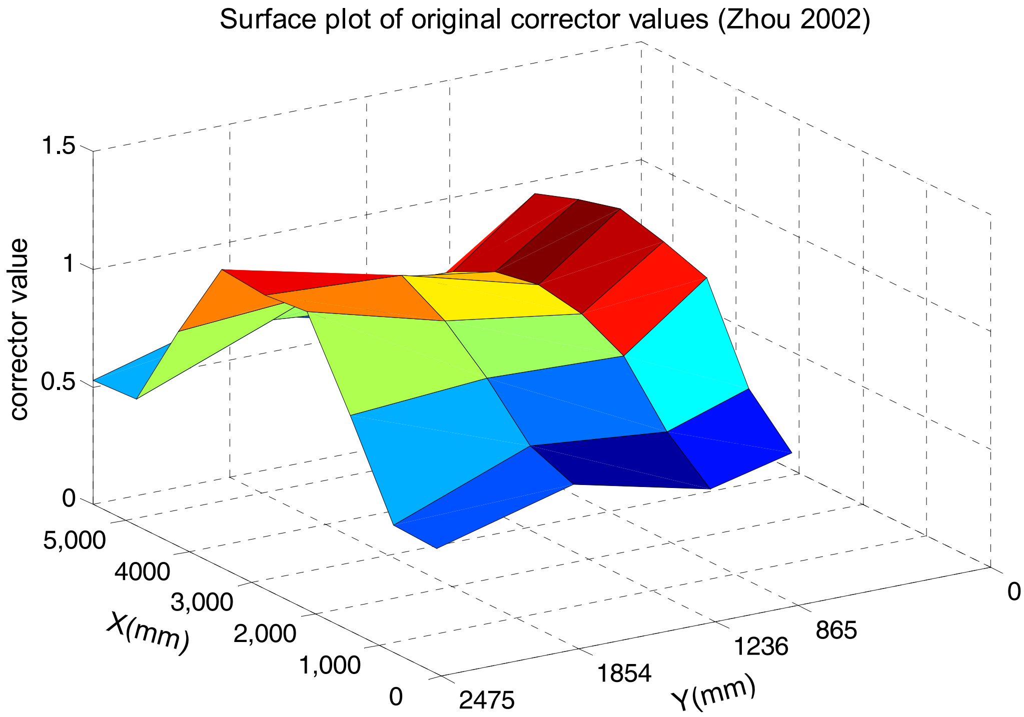

Figure 7 surface plot of correctors obtained by Zhou [1]

Zhou's corrector values were based on a direct comparison (a single step) of the FEA and experimental deflection values. In order to further improve the accuracy of the corrector values after a comprehensive study the following modification was introduced:

$$\psi_i = \frac{W_{FEA}^{i-1}}{W_{Exp}}, \quad \text{and} \quad D\psi_i = D\psi_{i-1} * (\psi_i)^m$$

Where:

i = number of iteration

m = a constant 0< m < 1.0 to refine the search for better match between experimental and FEA results.

The result of the investigation demonstrated that values of m<0.4 and up to 4 Iteration gives much better results.

Figure 8 shows corrector values obtained by the iteration method.

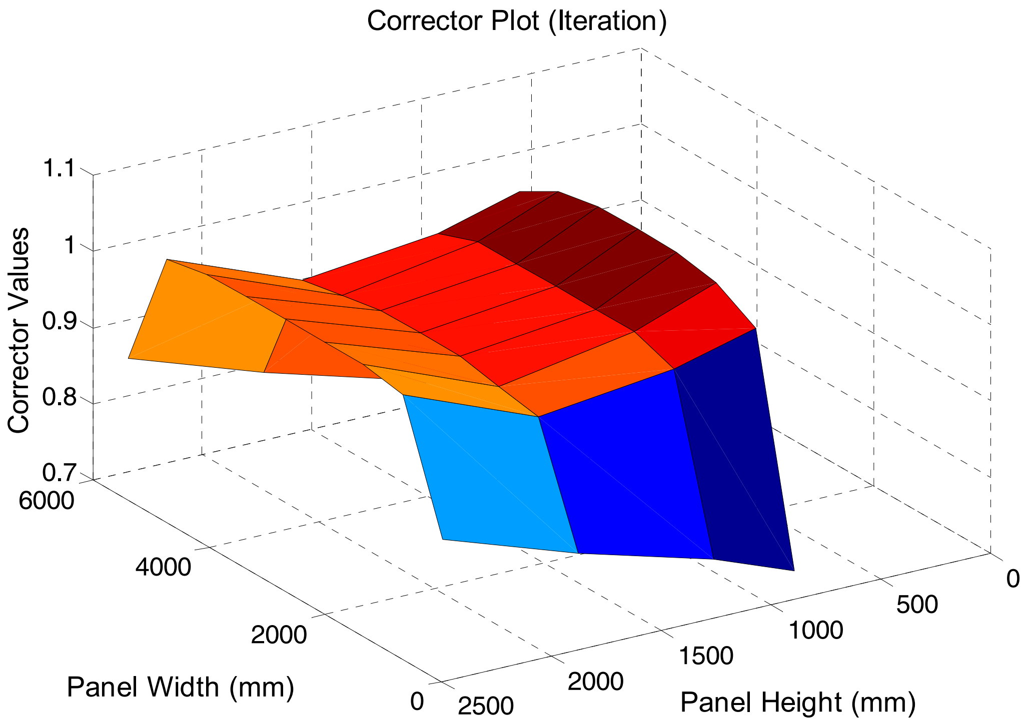

Figure 8 Surface plot of correctors obtained by iteration for different m

3.4 The Genetic Algorithm approach

A further investigation was carried out using genetic algorithms (GAs). In this investigation corrector values were directly determined by the GA. The variables in the GA were 36 corrector values at the locations of the laboratory measured deflection points and the objective was to minimise the total error between measured and FEA results at all locations on the panel. Although the GA minimised the error considerably, due to the high dimensionality of the problem (36 dimensions in this case) it was difficult to find a unique solution. It was decided to combine the GA and regression analysis results to get a better result.

3.5 Combining the GA and regression

In this method corrector values from several runs of the GA were collected and a regression analysis was performed in order to minimise the error between the FEA results and the measured deflection at each location on the panel individually. The tesults of this investigation are presented in Figure 9, and this was adopted as the corrector values for the base panel.

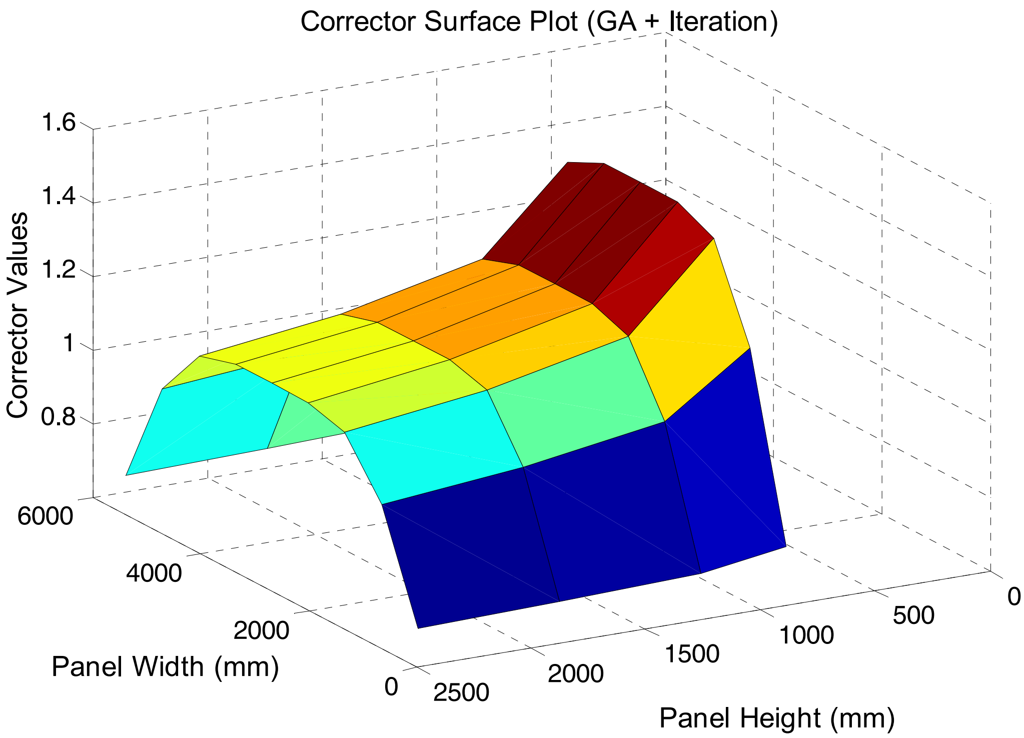

Figure 9 Surface plot of correctors obtained by the GA and iteration

4 Case studies

4.1 The base panel

Using the corrector values shown in Figure 9, the base panel was analysed using non-linear FEA program. The predicted failure load was 2.6 kN/m^2 which was an excellent match with the experimental failure load of 2.7 kN/m^2. Figure 10 shows a contour plot of the analytical failure pattern of this panel at 2.6 kN/m^2 load level. Once again this is similar to the experimental failure pattern shown in Figure 11.

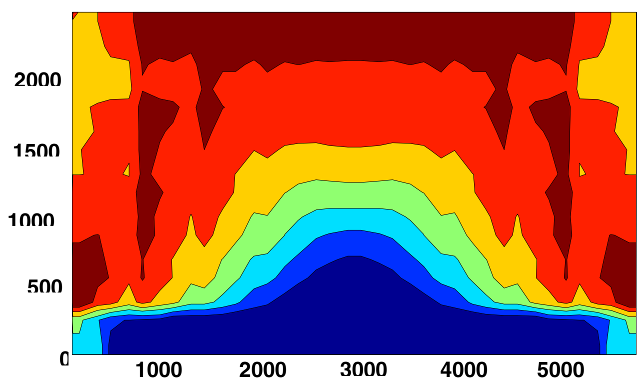

Figure 10 Predicted failure pattern of the base panel

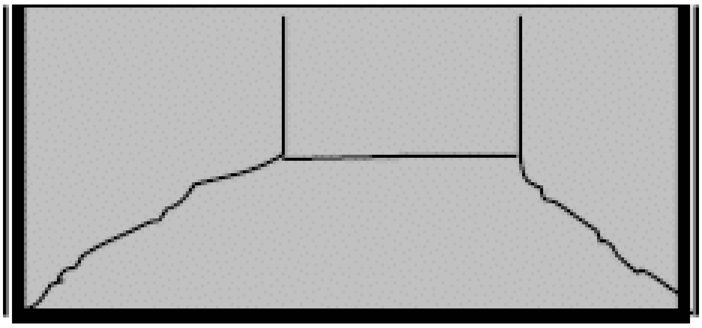

Figure 11 Experimental failure pattern of base panel

Figure 12 shows a comparison of the modified experimental and analytical load deflected shapes. There is a close similarity between the two surfaces.

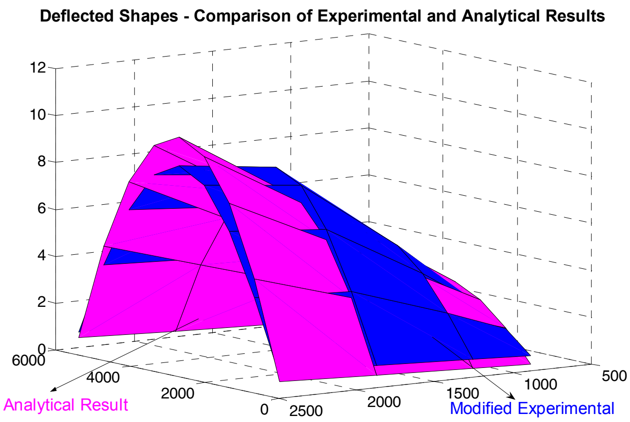

Figure 12 Surface plot of the experiment and analytical deflected shapes

4.2 Unseen panel with different size and boundary conditions

To demonstrate the generality and applicability of the methodologies described in this paper, cellular automata was used to establish corrector values at different locations on this unseen panel using similarity rules discussed in Zhou et al [3]. The corrector values were taken from the base panel as shown in Figure 9. The unseen panel was analysed using the same non-linear FEA program. The results of the analysis are discussed in this section.

Figures 13 and 14 show the analytical and experimental failure patterns of this unseen panel respectively. From the comparison of these two Figures it is clear that the analytical method was able to predict the failure pattern correctly. The analytical predicted failure load for this panel was 7.5 kN/m^2, which compares well with the experimental failure load of 7.0 kN/m^2.

Figure 15 shows a comparison of the experimental and analytical load deflected shapes. Both deflected shapes are similar, but the analytical model seems to be a bit stiffer than the actual panel. This could also be the effect of scaling factor as this unseen panel was half the size of the base panel. This aspect needs further investigation. It is worthwhile mentioning that the experimental records of this unseen panel showed that the right hand side of this panel had moved. This aspect has not been considered in the analysis.

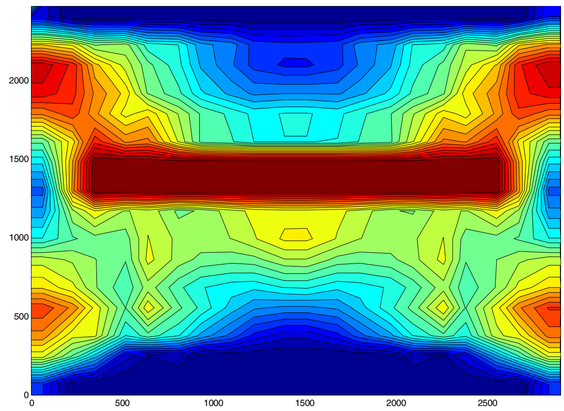

Figure 13 Predicted failure pattern of an unseen panel

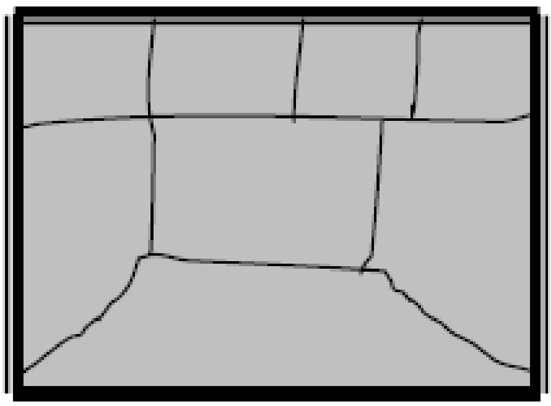

Figure 14 Experimental failure pattern of an unseen panel

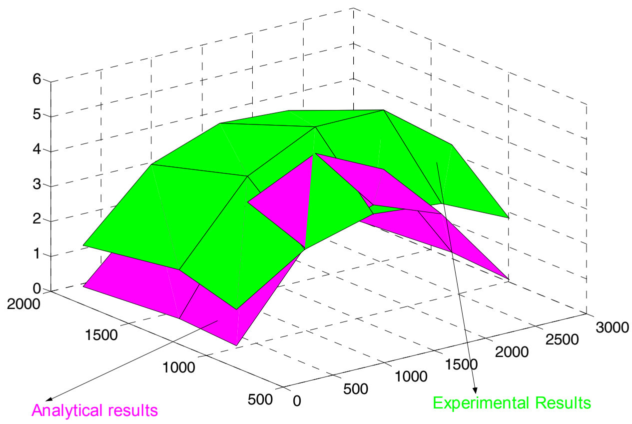

Figure 15 Surface plots of the experiment and analytical deflected shapes

5 Conclusions

Based on this investigation the following conclusions can be drawn:

- The failure load values were greatly improved.
- Load deflection curves at various locations on the panel were closely related to the experimental results.
- The failure pattern was similar to those of the experimental results and those of Zhou [1].
- The corrector values for 'unseen' panels, which were determined by the Cellular Automata, using zone similarity concepts greatly improved the prediction of failure load and load deflection values.
- Scaling rules proposed in this research was effective to model scaling effects due to changes between the 'base panel' and any 'unseen' panels.

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